CHOICE AND CONDITIONED REINFORCEMENT

EDMUND FANTINO, DEBRA FREED, RAY A. PRESTON, AND
WENDY A. WILLIAMS

UNIVERSITY OF CALIFORNIA-SAN DIEGO

A potential weakness of one formulation of delay-reduction theory is its failure to include a term for rate of conditioned reinforcement, that is, the rate at which the terminal-link stimuli occur in concurrent-chains schedules. The present studies assessed whether or not rate of conditioned reinforcement has an independent effect upon choice. Pigeons responded on either modified concurrent-chains schedules or on comparable concurrent-tandem schedules. The initial link was shortened on only one of two concurrent-chains schedules and on only one of two corresponding concurrent-tandem schedules. This manipulation increased rate of conditioned reinforcement sharply in the chain but not in the tandem schedule. According to a formulation of delay-reduction theory, when the outcomes chosen (the terminal links) are equal, as in Experiment 1, choice should depend only on rate of primary reinforcement; thus, choice should be equivalent for the tandem and chain schedules despite a large difference in rate of conditioned reinforcement. When the outcomes chosen are unequal, however, as in Experiment 2, choice should depend upon both rate of primary reinforcement and relative signaled delay reduction; thus, larger preferences should occur in the chain than in the tandem schedules. These predictions were confirmed, suggesting that increasing the rate of conditioned reinforcement on concurrent-chains schedules may have no independent effect on choice.

Key words: choice, conditioned reinforcement, concurrent schedules, concurrent-chains schedules, tandem schedules, delay-reduction theory, reinforcement frequency, key peck, pigeons

According to delay-reduction theory, the effectiveness of a stimulus as a conditioned reinforcer may be predicted most accurately by calculating the reduction in the length of time to primary reinforcement measured from the onset of the preceding stimulus (Fantino, 1969, 1977, 1981; Fantino & Davison, 1983; Killeen & Fantino, 1990; Squires & Fantino, 1971). The simplest form of the delay-reduction theory may be stated as:

Reinforcement strength of Stimulus A

$$= f\left(\frac{T - t_A}{T}\right) \qquad (1)$$

where t_A is the temporal interval between the onset of Stimulus A and primary reinforcement and T is the total time between reinforcer presentations. Expressed differently, the greater the improvement, in terms of temporal proximity or waiting time to reinforcement, that is correlated with the onset of a stimulus, the more effective that stimulus will be as a conditioned reinforcer. Although the hypothesis has been extended to areas such as self-control (Ito & Asaki, 1982; Navarick & Fantino, 1976), elicited responding (Fantino, 1982), three-alternative choice (Fantino & Dunn, 1983), observing (Case & Fantino, 1981; Fantino & Case, 1983), and operant analogues to foraging (Abarca & Fantino, 1982; Fantino & Abarca, 1985), the hypothesis was first developed to account for choice between two variable-interval (VI) schedules of reinforcement in the concurrent-chains procedure developed by Autor (1960, 1969) and Herrnstein (1964).

Squires and Fantino (1971) incorporated the delay-reduction account of conditioned reinforcement into a general model of choice that predicted preference as a joint function of the values of conditioned reinforcement and the rates of primary reinforcement such that:

$$\frac{B_1}{B_1 + B_2} = \frac{r_1(T - t_1)}{r_1(T - t_1) + r_2(T - t_2)}$$

$$\text{for } t_1 < T \text{ and } t_2 < T,$$

$$= 1, \quad \text{for } t_1 < T, t_2 > T,$$

$$= 0, \quad \text{for } t_1 > T, t_2 < T, \qquad (2)$$

where B_1 and B_2 are the choice responses on the left and right keys, respectively, measured in the concurrently available initial links (choice phase), r_1 and r_2 are the overall rates of food on the left and right keys, respectively, T is the average overall time to food measured from the onset of the choice phase, and t_1 and t_2 are the average times (or delays) during the terminal links (or outcome phase) on the left and right keys, respectively. The term $(T - t_x)$ represents the degree to which a terminal-link stimulus is correlated with a reduction in time to primary reinforcement.

The inclusion of the terms r_1 and r_2 acknowledges that reinforcement experienced more frequently has more impact on the behavior upon which it is contingent. Moreover, it permits the equation to reduce to the familiar matching law (Herrnstein, 1970) when the durations of the terminal links are zero ($t_1 = t_2 = 0$). Delay-reduction theory has been supported in cases in which its predictions have been pitted against predictions from competing viewpoints. For example, Dunn and Fantino (1982) pitted delay reduction against rate of reinforcement (t_x) as potential controlling variables in a concurrent-chains experiment and found that rate of reinforcement accounted for choice if and only if its predictions were consistent with those of delay reduction. In tests of their three-alternative version of Equation 2, Fantino and Dunn (1983) showed that Luce's choice axiom (Luce, 1977), also known as the "independence from irrelevant alternatives" axiom of formal choice theories in economics and psychology, was consistent with choice if and only if its predictions were consistent with those of delay reduction.

More recently, LaFiette and Fantino (1989) have shown that the delay-reduction theory makes accurate predictions under radically different deprivation conditions (i.e., in both open and closed economies; after Hursh, 1980), and Fantino and Preston (1988) have applied delay reduction successfully to a foraging analogue in which the following counterintuitive prediction was supported: As the less profitable of two outcomes was encountered more frequently (with the absolute encounter rate for the more profitable kept constant) there came a point at which subjects accepted it less frequently; that is, greater accessibility led to decreased acceptability. Finally, Wixted (1989) has shown that delay-reduction principles can help to account for the serial-position effect in studies of short-term memory.

Note that Equation 2 does not include a term for the rate of conditioned reinforcement (i.e., the rate at which the terminal-link stimuli occur). This feature is a potential weakness of Squires and Fantino's (1971) general choice model, because some research indicates that the frequency of conditioned reinforcement affects an organism's responding in a manner similar to frequency of primary reinforcement (e.g., Nevin & Mandell, 1978; Zimmerman, 1963; Zimmerman, Hanford, & Brown, 1967). Thus, Nevin (1973, p. 165) has concluded that "the frequency of conditioned reinforcement affects performance in much the same way as the frequency of primary reinforcement" and Killeen (1982) has argued that choice responses in the choice phase of concurrent-chains schedules are affected both by primary reinforcement, which is delayed, and by immediate conditioned reinforcement.

Whether or not frequency of conditioned reinforcement affects choice beyond the effect exerted by frequency of primary reinforcement has not been determined directly in the concurrent-chains procedure. One implication of Equation 2 is that frequency of conditioned reinforcement (again, the rate at which terminal-link stimuli occur) affects choice only indirectly through changes in the interreinforcement interval (the rate of primary reinforcement, r_1 and r_2 in Equation 2). The present study has two broad aims: (a) to assess whether or not frequency of conditioned reinforcement affects choice independent of its role in affecting the absolute rates of primary reinforcement (r_1 and r_2), and (b) to assess the relative contributions of the delay-reduction and primary-reinforcement factors in Equation 2, that is, $(T - t_x)$ and r_x, respectively. It should be stressed that the fundamental notion of delay reduction is expressed by Equation 1 (i.e., in the expression of the delay-reduction kernel). Equation 2 predicts how conditioned reinforcement, expressed in terms of delay reduction, and primary reinforcement combine to account for preference in concurrent and concurrent-chains schedules. Modification of Equation 2 does not necessarily require revision of Equation 1.

Conditions in the present experiment involve comparisons of modified concurrent-chains schedules and comparable concurrent-

tandem schedules. In typical concurrent-chains schedules, entry into one terminal link is accompanied by the darkening of the other response key, which then remains inoperative until reinforcement has been delivered. If a concurrent-tandem schedule were to operate in this manner, however, the darkening of one response key would serve as a cue for terminal-link entry, thereby converting the tandem to a chain. To retain the essential feature of a tandem schedule—that no stimulus change is correlated with the onset of a new link—the concurrent-tandem schedules used in the present comparisons were independent and operative throughout (i.e., when the subject entered the terminal link on one response key, the other response key remained lit and operative). Therefore, to maintain comparability with the tandem schedules, the concurrent-chains schedules were also independent and operative throughout (of course, a stimulus change occurred on a response key as the subject entered a terminal link, the essential feature of a chain schedule). This type of modified concurrent-chains schedule was used previously by Fantino and Duncan (1972).

In applying Equation 2 to concurrent-tandem schedules, t_1 and t_2 are 0, because, according to delay reduction, a stimulus change is required. Thus, the right side of Equation 2 reduces to $r_1/(r_1 + r_2)$ and Equation 2 requires simple matching of choice proportions to (primary) reinforcer proportions.

Two sets of conditions were examined. In both, the initial link was shortened on only one of two concurrent-chains schedules and on only one of two corresponding concurrent-tandem schedules. Shortening the initial link increases the rate of primary reinforcement on both the chain and tandem schedules. This same manipulation, however, will affect the rate of conditioned reinforcement only on the chain schedule, because distinctive stimuli—the putative conditioned reinforcers—do not signal terminal-link onset in tandem schedules. Thus, if rate of conditioned reinforcement does indeed affect choice, preference for the alternative associated with the shorter initial link should be greater on the chain schedule than on the equivalent tandem schedule. On the other hand, if the frequency of conditioned reinforcement is effective only through changing the overall rate of primary reinforcement (r_1 and r_2 in Equation 2), preference on the

chain and tandem schedules should be equivalent unless there is a contribution of delay reduction ($T - t_x$ in Equation 2). In Experiment 1, the terminal-link durations were equal in all conditions ($t_1 = t_2$ in Equation 2). Thus, $T - t_1 = T - t_2$ and, according to Equation 2, choice should depend upon only the overall rates of primary reinforcement, because, for both the tandem and chain schedules, the right side of Equation 2 reduces to $r_1/(r_1 + r_2)$. In Experiment 2, however, the terminal-link durations were unequal. Thus, choice should then depend upon both rate of primary reinforcement and relative signaled delay reduction. Relative delay reduction could not alter preference in the tandem schedules because entries into the terminal links were unsignaled; hence choice should be under control only of changes in rate of primary reinforcement in the tandem case. In terms of the chain and tandem comparisons, therefore, preference should be equivalent in Experiment 1, but larger preferences for the shorter terminal link should occur in the chain schedules than in the tandem schedules in Experiment 2. If choice were consistent with these predictions of Equation 2, the results would also be consistent with the implication that frequency of conditioned reinforcement is effective only through changing the overall rate of primary reinforcement.

EXPERIMENT 1

METHOD

Subjects

Four experimentally naive adult male Indian Mondian pigeons, maintained at 80% of free-feeding body weights, served as subjects. In addition, 3 subjects that first served in Experiment 2 were exposed to selected conditions in Experiment 1. Water and grit were available continuously in each bird's home cage.

Apparatus

Subjects were studied in four identical cylindrical chambers (36 cm high and 33 cm in diameter). Three response keys (2 cm in diameter) were located 24 cm above the mesh floor and 7 cm apart, center to center. Only the outer two keys were operative and could be transilluminated from the rear with white, red, or amber lights. A force of approximately 0.10 N was required to operate the response

keys and produced an audible feedback click. A white houselight was located 8 cm above the center key and was illuminated except during reinforcer presentations. The food hopper opening (5 cm high and 5 cm wide) was located 16 cm below the center key. Reinforcement was delivered via a solenoid-operated food hopper and consisted of 3-s access to milo. During reinforcer presentations, the houselight and response keys became dark and the hopper opening was illuminated. A ventilating fan, which also provided masking noise, was located in the lid of the chamber. A Digital Equipment Corporation PDP-8E® computer, located in an adjacent room, programmed events in the chamber and recorded session data.

Procedure

Subjects first were trained to approach and eat from the illuminated hopper; then responding was autoshaped in the presence of white, red, and amber keylights (both assignment of color and key was on a random trial-by-trial basis). The subjects subsequently were exposed to a series of VI schedules in which the mean interreinforcement interval (IRI) was gradually increased until responding was maintained on a VI 60-s schedule in the presence of a white keylight.

For each bird, key pecks were reinforced according to a concurrent-chains VI VI schedule of reinforcement or a concurrent-tandem VI VI schedule of reinforcement. The IRIs on all VI schedules were based on Fleshler and Hoffman (1962) distributions. For both the concurrent-chains and concurrent-tandem schedules, responses that produced entry into a terminal link on one key did not terminate the stimulus or schedule associated with the other key. Thus, four combinations of chain links, or states, were possible: (a) concurrent initial links, (b) left initial link concurrent with right terminal link, (c) left terminal link concurrent with right initial link, and (d) concurrent terminal links. As can be seen in Figure 1, entry into a terminal link during a concurrent chain (Panel B) was signaled by a change in key color (in this case, from white to amber or red), while there were no differential stimuli associated with the links of the tandem schedules. A 1.5-s changeover delay (COD) was in effect throughout the experi-

ment; this prevented responses on one key from being followed by reinforcement on the other key within 1.5 s of a changeover. Sessions terminated after 40 reinforcers.

For Birds Y34 and Y33, the first condition was a tandem schedule in which the initial-link schedules were equal VI 60 s with equal VI 30-s terminal links. Each keylight was always illuminated white. Each condition was in effect for a minimum of 15 sessions. Conditions were changed when responding was considered stable according to the following criterion: On the 15th day and every day following, the last nine sessions were divided into three blocks of three consecutive sessions; the means of the choice proportions for each block of sessions were calculated, and responding was considered stable when the means of the three blocks differed by no more than .05 and there was no increasing or decreasing trend evident in the means (i.e., neither $M_1 > M_2 > M_3$ nor $M_1 < M_2 < M_3$). In the second condition, which was also a tandem comparison, one of the VI 60-s initial links was shortened to a VI 10-s schedule so that a VI 60-s initial link leading to a VI 30-s terminal link was arranged on one key and a VI 10-s initial link leading to a VI 30-s terminal link was arranged on the other. Position of reinforcement schedules on the response keys was counterbalanced across these subjects. The third and fourth conditions corresponded to the first and second, except with chain schedules; thus, colored keylights signaled entry into the terminal links. For Bird Y34, the terminal link associated with the shorter initial link corresponded to a red keylight, whereas the other terminal link was signaled by an amber keylight. Key colors were reversed for Bird Y33.

Two additional birds (Y32 and Y40) were matched to Y34 and Y33 with respect to schedule values and key colors. However, Y32 and Y40 began the sequence of conditions with the chain schedules, followed by the tandem schedules to counterbalance order.

Although the scheduled values in the corresponding tandem and chain schedules were equal, the obtained IRIs were not. Thus, following the four conditions discussed above, all 4 birds were exposed to two tandem schedules in which the scheduled IRIs equaled the obtained IRIs from the corresponding chain schedules. The actual scheduled values dif-
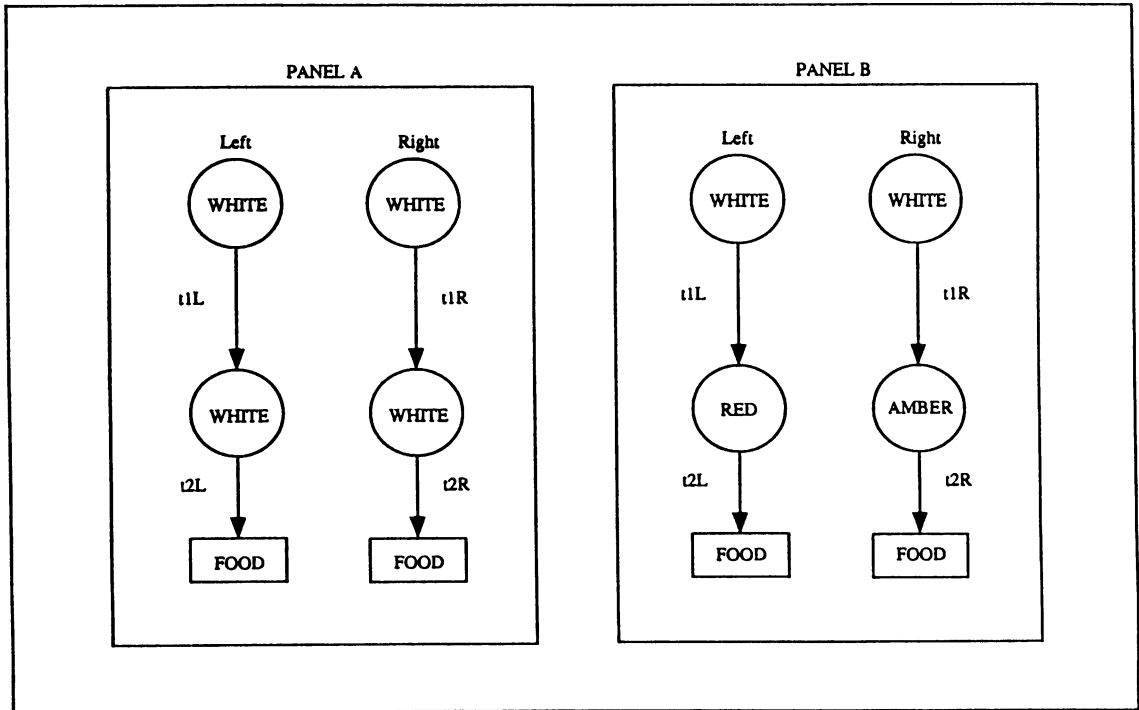
Fig. 1.   The concurrent-tandem and concurrent-chains procedures. Panel A illustrates the sequence of events in a concurrent tandem, in which the same stimulus is present on each key throughout. Panel B shows the sequence of events in a concurrent chain. Note that entry into each terminal link is signaled by a unique stimulus. During both choice and outcome phases of one schedule, the other schedule remains operative in both the chain and tandem procedures.

fered for each subject (because the values were based on the obtained values for each subject in the earlier chain-schedule conditions) and are shown in Table 1 (yoked tandem conditions). Table 1 also shows the order of conditions and the number of sessions in each for each subject. Following the yoked tandem conditions, all subjects were exposed to a replication of the concurrent-chains conditions. Three additional subjects, which had first participated in Experiment 2, were also exposed to two chain conditions and two corresponding yoked tandem conditions.

RESULTS AND DISCUSSION

Mean choice proportions (responses in the shortened initial link divided by the sum of responding in both initial links) from the last nine sessions of each condition for each subject are shown in Table 2. These choice proportions are based on all time in which initial links were available concurrently (i.e., responses made to an initial link concurrent with

a terminal link are not included). Thus, choice in this modified procedure was measured as in standard concurrent-chains schedules. Choice responses were measured in a strictly identical fashion for the tandem comparisons.

Although the scheduled IRIs in the yoked tandem conditions were equated to the obtained intervals on the corresponding chain conditions, the obtained intervals were expected to be longer. These obtained intervals are shown in Table 2. Although the durations were indeed systematically longer, the discrepancies did not systematically favor either key. Moreover the discrepancies were considerably smaller than the corresponding differences between the chain schedules and the basic (unyoked) tandem schedules. Thus, in discussing the results we will focus on comparisons between the chain and yoked tandem schedules. Examination of the data in Table 2, however, shows that our conclusions are supported equally well by comparisons with the basic tandem schedules.

Table 1

Scheduled conditions, sequence of conditions, and number of sessions per condition for each subject in Experiment 1.

Bird	Condition order	Initial link VI left/right	Terminal link VI left/right	Number of sessions
Y34	Tandem	60/60	30/30	22
		60/10	30/30	16
	Chain	60/60	30/30	20
		60/10	30/30	15
	Yoked tandem	106/67	33/26	21
		151/24	29/29	20
	Chain replication	60/60	30/30	16
		60/10	30/30	40
Y33	Tandem	60/60	30/30	19
		10/60	30/30	38
	Chain	60/60	30/30	37
		10/60	30/30	24
	Yoked tandem	71/90	35/33	15
		21/166	28/31	16
	Chain replication	60/60	30/30	15
		10/60	30/30	25
Y32	Chain	60/60	30/30	26
		60/10	30/30	17
	Tandem	60/60	30/30	18
		60/10	30/30	32
	Yoked tandem	82/82	30/28	15
		106/34	28/32	15
	Chain replication	60/60	30/30	23
		60/10	30/30	15
Y40	Chain	60/60	30/30	24
		10/60	30/30	19
	Tandem	60/60	30/30	15
		10/60	30/30	15
	Yoked tandem	74/72	33/27	15
		30/95	30/30	15
	Chain replication	60/60	30/30	16
		10/60	30/30	27
B285	Chain	120/120	15/15	17
		10/120	15/15	33
	Yoked tandem	129/142	15/17	31
		17/160	15/16	18
Y35	Chain	60/60	30/30	15
		60/10	30/30	38
	Yoked tandem	103/70	33/30	32
		124/27	27/33	16
Y37	Chain	120/120	15/15	15
		10/120	15/15	23
	Yoked tandem	135/128	16/14	15
		18/216	14/15	45

When the initial link leading to one of two equal terminal links was shortened did preference increase more in the chain schedule than in the yoked tandem comparison? The mean increases in the chain condition (averaged across replications for the 4 subjects exposed to the chain conditions twice) and in the yoked tandem condition are shown in Table 3 for each of 7 subjects. For only 3 subjects was the increase in preference greater in the chain conditions than in the tandem conditions (Y34, Y40, and Y37). The mean increase across seven subjects was .07 for the chain conditions and .08 for the yoked tandem conditions (and .14 for the 4 subjects in the simple tandem condition). Thus, there is no suggestion that the six-fold increase in rate of conditioned reinforcement (a 12-fold increase for Subjects B285 and Y37) increased preference beyond the increase attributable to the accompanying (though relatively smaller) increase in rate of primary reinforcement also occurring in the tandem schedules.

Because the present procedure differs substantially from standard concurrent-chains schedules, Equation 2 may not make accurate quantitative predictions for the modified concurrent-chains schedules. In fact, the mean deviation (averaged over the 22 chain conditions) of the obtained from predicted choice proportions was .11 when the predictions were based, as is usual, on the scheduled IRIs and .10 when the predictions were based on the obtained IRIs (individual data available from the business manager of *JEAB,* upon request).

A methodological issue that warrants discussion involves the possibility that, with the very short initial links used in some conditions of Experiment 1 (VI 10-s schedules), little opportunity occurred for multiple responses to one key. However, the average number of initial-link responses per terminal-link entry on the VI 10-s initial link was considerably above 1 (range of 6.4 to 18.5 responses per entry with a mean of 11.8 in the chain schedules, and a range of 4.6 to 13.1 with a mean of 9.4 in the tandem schedules; data averaged over the last nine sessions of each condition with a VI 10-s initial link).

EXPERIMENT 2

Experiment 1 assessed the contribution of the frequency of conditioned reinforcement to choice behavior. The results indicated that the frequency of conditioned reinforcement does not affect choice directly, in keeping with Equation 2, which implies that frequency of conditioned reinforcement does not directly affect choice. In Experiment 1 the scheduled terminal-link durations were always equal.

Table 2

Mean obtained choice proportions for the shortened initial link per condition for each subject in Experiment 1. Also shown are schedules and obtained interreinforcement intervals (IRI) for each alternative (left and right) and for each condition overall.

Condition	Bird	Scheduled IRI left/right	Obtained IRI left/right	Scheduled overall IRI	Obtained overall IRI	Obtained choice proportions[a]
Tandem: equal initial links	Y34	90/90	106/102	60	69	.44
	Y33	90/90	106/106	60	71	.48
	Y32	90/90	101/108	60	71	.55
	Y40	90/90	94/99	60	64	.54
			Grand Mean:	60	69	.50
Tandem: unequal initial links	Y34	90/40	127/44	39	47	.80
	Y33	40/90	46/116	39	48	.54
	Y32	90/40	119/51	39	53	.51
	Y40	40/90	45/93	39	43	.74
			Grand Mean:	39	48	.65
Chain: equal initial links	Y34	90/90	139/93	60	71	.60
	Y33	90/90	106/123	60	74	.62
	Y32	90/90	112/110	60	70	.53
	Y40	90/90	107/99	60	66	.49
	Y35	90/90	136/100	60	73	.72
	B285	135/135	144/159	75	83	.64
	Y37	135/135	151/142	75	81	.52
			Grand Mean:	64	74	.59
Chain: unequal initial links	Y34	90/40	180/53	39	50	.77
	Y33	40/90	49/197	39	49	.73
	Y32	90/40	134/66	39	56	.45
	Y40	40/90	60/125	39	53	.56
	Y35	90/40	151/60	39	52	.68
	B285	25/135	32/176	39	31	.71
	Y37	25/135	32/231	39	31	.79
			Grand Mean:	39	46	.69
Chain replication: equal initial links	Y34	90/90	117/104	60	70	.62
	Y33	90/90	100/108	60	67	.51
	Y32	90/90	105/100	60	68	.40
	Y40	90/90	97/102	60	64	.59
			Grand Mean:	60	67	.53
Chain replication: unequal initial links	Y34	90/40	185/53	39	48	.80
	Y33	40/90	60/123	39	52	.38
	Y32	90/40	128/65	39	55	.40
	Y40	40/90	57/118	39	53	.65
			Grand Mean:	39	52	.56
Yoked tandem: yoked to equal initial link chain	Y34	139/93	146/96	70	76	.57
	Y33	106/123	107/132	74	77	.64
	Y32	112/110	129/133	70	84	.41
	Y40	107/99	123/106	66	74	.52
	Y35	136/100	156/119	73	86	.43
	B285	144/159	141/174	84	87	.60
	Y37	151/142	187/149	56	94	.49
			Grand Mean:	70	83	.52
Yoked tandem: yoked to unequal initial link chain	Y34	180/53	195/61	50	61	.66
	Y33	49/197	59/237	47	62	.67
	Y32	134/66	148/72	57	62	.55
	Y40	60/125	65/126	53	58	.57
	Y35	151/60	176/78	54	50	.49
	B285	32/176	40/188	30	43	.75
	Y37	32/231	38/242	44	48	.52
			Grand Mean:	48	55	.60

[a] Obtained choice proportions averaged for the shortened initial link over the last nine sessions.

Table 3

Preference changes in both the chain and tandem schedule conditions, following the shortening of one initial link, in Experiment 1.

Bird	Chain[a]		Yoked tandem		Chain	Yoked tandem
	Mean preference for equal initial links[b]	Mean preference for unequal initial links[b]	Mean preference for equal initial links[b]	Mean preference for unequal initial links[b]	Mean preference increase	Mean preference increase
Y34	.61	.79	.57	.66	.18	.09
Y33	.57	.56	.64	.67	−.01	.03
Y32	.47	.43	.41	.55	−.04	.14
Y40	.54	.61	.52	.57	.07	.05
Y35	.72	.68	.43	.49	−.04	.06
B285	.64	.71	.60	.75	.07	.15
Y37	.52	.79	.49	.52	.27	.03
M	.58	.65	.52	.60	.07	.08

[a] Proportions averaged across chain and chain replication conditions where applicable.
[b] Preference averaged for shortened initial link over last nine sessions.

Hence there was no differential delay reduction, that is, $T - t_1 = T - t_2$ in Equation 2, and choice was determined only by the relative IRIs. Because these were comparable for the tandem and corresponding chain schedules, the increments in preference where one terminal link was entered more frequently should have been—and were—equivalent for the tandem and chain schedules. When the terminal links were unequal, however, greater delay reduction was associated with the shorter terminal link. As a result, preference for the shorter terminal link should be greater in the chain case than in the corresponding tandem schedule (in which there is no signaled reduction). Thus, although Equation 2 predicted no difference in preference when comparing equivalent chain and tandem schedules in Experiment 1, clear differences are predicted when the terminal links are unequal, as in Experiment 2.

METHOD

Subjects

Four experimentally naive adult male Indian Mondian pigeons, maintained at 80% of free-feeding body weights, served as subjects. Water and grit were available continuously in each bird's home cage.

Apparatus

Subjects were studied in four identical rectangular chambers (32 cm high, 35 cm wide, and 36 cm deep). Three response keys (2.5 cm in diameter) were located 23 cm above the mesh floor and 7.25 cm apart, center to center. Only the outer two keys were operative and could be transilluminated from the rear with white, red, or amber lights. A force of approximately 0.15 N was required to operate the response keys and produced an audible feedback click. A white houselight was located 5 cm above the center key and was illuminated except during reinforcer presentations. The food hopper opening (5 cm high and 6 cm wide) was located 9.5 cm below the center key. Other details were the same as in Experiment 1.

Procedure

With the exception of schedule values, the pretraining and the concurrent-chains and tandem procedures were identical to those employed in Experiment 1. The first condition for all birds was conducted for a minimum of 15 days. The same stability criterion as that used in Experiment 1 was also used in Experiment 2.

For Birds B29 and B285, the first experimental condition consisted of a concurrent-tandem schedule with equal VI 60-s initial links and terminal links of VI 10 s and VI 30 s. Each keylight was always illuminated white. Once stability was reached, the second condition was implemented. In this condition, the initial link associated with the shorter terminal link was shortened to a VI 30-s schedule (i.e., the VI 60-s initial link associated with the VI 10-s terminal link was changed to a VI 30-s

schedule), while the initial link leading to the longer terminal link was unchanged. Position of reinforcement schedules on the response keys was counterbalanced across these subjects. This condition also constituted a tandem comparison and was in effect for a minimum of 15 sessions, upon which the same stability criterion was imposed.

The third condition consisted of the same schedule values as in the first condition, but with a concurrent-chains procedure in which colored stimuli signaled entry into the terminal links. In other words, the initial links consisted of two VI 60-s schedules, which led to VI 30-s and VI 10-s schedules in the terminal links. For Bird B29, the VI 30-s terminal link was always associated with a red keylight, whereas the VI 10-s terminal link corresponded to an amber keylight. These colors were reversed for Bird B285. VI 60-s initial links were associated with white keylights.

The fourth condition corresponded to the second, in that the VI 60-s initial link associated with the VI 10-s terminal link was shortened to a VI 30-s schedule, so that a VI 30-s initial link now resulted in a VI 10-s terminal link and the VI 60-s initial link led to the VI 30-s terminal link; but, as in Condition 3, a concurrent-chains schedule was used. Terminal-link key colors were the same as in the third condition.

Two other birds (Y35 and Y37) were matched to the first two with respect to schedule values and key colors, but the order of presentation was reversed so that these birds began with the two chain comparisons and finished with the two tandem comparisons. This counterbalanced order of condition presentation. Their first condition was also conducted for a minimum of 20 sessions, and each following condition was in effect for a minimum of 15 sessions.

Following the four conditions described above, each of the 4 subjects was exposed to two yoked tandem conditions in which the scheduled IRIs were equal to the obtained IRIs from the corresponding chain conditions. These values, along with the order of conditions for each subject and the number of sessions in each, are shown in Table 4.

RESULTS AND DISCUSSION

Table 5 presents the mean choice proportions for each subject averaged over the last nine sessions of each condition. Also presented

Table 4

Scheduled conditions, sequence of conditions, and number of sessions per condition for each subject in Experiment 2.

Bird	Condition order	Initial link VI left/right	Terminal link VI left/right	Number of sessions
B29	Tandem	60/60	30/10	18
		60/30	30/10	16
	Chain	60/60	30/10	18
		60/30	30/10	19
	Yoked tandem	119/67	35/10	17
		459/34	40/10	18
B285	Tandem	60/60	10/30	18
		30/60	10/30	14
	Chain	60/60	10/30	15
		30/60	10/30	22
	Yoked tandem	68/105	10/29	16
		33/169	10/48	16
Y35	Chain	60/60	30/10	19
		60/30	30/10	15
	Tandem	60/60	30/10	21
		60/30	30/10	18
	Yoked tandem	122/64	31/10	15
		406/43	35/11	21
Y37	Chain	60/60	10/30	16
		30/60	10/30	15
	Tandem	60/60	10/30	18
		30/60	10/30	13
	Yoked tandem	66/96	09/28	15
		35/190	10/38	16

are the mean IRIs for each component on each key and the mean overall IRI (summed over the two components on a key) for each key.

In this experiment, Equation 2 requires larger choice proportions in the chain than in the corresponding tandem schedules. In fact, for each of 4 subjects, the choice proportion in each of the two chain conditions was higher than the corresponding choice proportions in either the tandem or yoked tandem conditions. As shown in Table 5, the mean choice proportions, averaged over subjects, were .53, .62, and .80 in the tandem, yoked tandem, and chain conditions, respectively, prior to shortening of one initial link, and were .61, .79, and .94 in the tandem, yoked tandem, and chain conditions in which one initial link was halved.

One may again ask how close the predictions of Equation 2 came to accounting for the data in the modified concurrent-chains schedules. The mean deviation (averaged over the eight chain conditions) of the obtained from predicted choice proportions was .10 when the pre-

Table 5

Mean choice proportions for the short (or left) initial link per condition for each subject in Experiment 2. Also shown are scheduled and obtained interreinforcement intervals (IRI) for each alternative (left and right), and for each condition overall.

Condition	Bird	Pro- grammed IRI left/right	Obtained IRI left/right	Pro- grammed total IRI	Obtained total IRI	Obtained choice pro- portions[a]
Tandem:	B29	90/70	94/87	50	59	.48
equal initial links,	B285	70/90	83/100	50	60	.50
unequal terminal links	Y35	90/70	117/78	50	61	.55
	Y37	70/90	77/102	50	58	.60
			Grand Mean:	50	60	.53
Tandem:	B29	90/40	100/50	37	45	.62
unequal initial inks,	B285	40/90	52/107	37	47	.60
unequal terminal links	Y35	90/40	114/50	37	51	.52
	Y37	40/90	47/111	37	46	.69
			Grand Mean:	37	47	.61
Chain:	B29	90/70	152/76	50	61	.83
equal initial links,	B285	70/90	77/132	50	59	.78
unequal terminal links	Y35	90/70	147/72	50	60	.82
	Y37	70/90	74/123	50	55	.77
			Grand Mean:	50	59	.80
Chain:	B29	90/40	499/45	37	82	.97
unequal initial links,	B285	40/90	43/217	37	57	.93
unequal terminal links	Y35	90/40	441/54	37	54	.95
	Y37	40/90	45/228	37	54	.92
			Grand Mean:	37	62	.94
Yoked tandem:	B29	154/77	170/89	62	75	.69
yoked to equal initial link chain	B285	78/134	88/164	59	76	.66
	Y35	153/74	178/83	60	75	.52
	Y37	75/124	82/131	56	64	.61
			Grand Mean:	59	73	.62
Yoked tandem:	B29	499/45	567/49	44	57	.81
yoked to unequal initial link chain	B285	43/217	45/337	44	91	.87
	Y35	441/54	429/50	52	67	.71
	Y37	45/228	53/261	44	70	.77
			Grand Mean:	46	71	.79

[a] Obtained choice proportions averaged for the shortened initial link over the last nine sessions.

dictions were based on the scheduled IRIs and .03 when the predictions were based on the obtained IRIs (individual data available from the business manager of *JEAB*, upon request).

GENERAL DISCUSSION

According to Equation 2, when the outcomes chosen are equal (as in Experiment 1) choice should depend only on rate of primary reinforcement (r_x in Equation 2) because delay reduction is not a factor ($T - t_1 = T - t_2$), be it signaled (as in chain schedules) or unsignaled (as in tandem schedules). One implication is that rate of conditioned reinforcement should not affect choice. These predictions

were confirmed in Experiment 1: Choice was comparable for comparable chain and tandem schedules even when schedules were altered so as to provide a six-fold increase in rate of conditioned reinforcement on the chain as opposed to the tandem schedule. In Experiment 2, the outcomes chosen were unequal. According to Equation 2, choice should then depend upon both rate of primary reinforcement and relative delay reduction signaled by the stimuli associated with the terminal links of the chains. Relative delay reduction could not alter performance in the tandem schedules because entries into the terminal links were unsignaled; choice in the tandem schedules should be under the control solely of changes in rate of primary

reinforcement. Thus, in Experiment 2, larger preferences should occur for the shorter terminal link in the chain schedules than in the tandem schedules. This prediction was also confirmed.

According to the delay-reduction hypothesis, the terminal-link stimuli in concurrent-chains schedules function as conditioned reinforcers when their onset signals a reduction in time to primary reinforcement. Based on many investigations of delay reduction and on other studies with concurrent-chains schedules (e.g., Dunn & Spetch, 1990; Royalty, Williams, & Fantino, 1987; Williams & Dunn, 1991), there is little question that such terminal-link stimuli function as conditioned reinforcers. If so, one might expect that increasing the frequency of these stimuli should affect choice. However, according to Equation 2, the frequency of the terminal-link stimuli should affect choice only insofar as shortening the initial link also, of necessity, increases the frequency of primary reinforcement (for a version of delay reduction that could accommodate effects of conditioned reinforcement frequency, see Fantino, Preston, & Dunn, in press). The results of the present study are consistent with Equation 2, in that increasing the frequency of these conditioned reinforcers did not have an independent effect on choice. It should be noted that models of choice that include a role for frequency of conditioned reinforcement are not necessarily weakened by the present results. In particular, it is not clear how to scale the values of the conditioned reinforcers (provided by the terminal links of concurrent chains) relative to the primary reinforcers provided on each key. If the terminal-link values are small relative to the value of food, then the effects of differences in terminal-link frequencies may have been masked by the greater effect of primary reinforcement frequencies. Certainly, depending on the assumptions made, it is possible to predict the present results with models that assume an effect of the frequencies of conditioned reinforcement. The present results suggest that their effects may be small at best, at least in conditions in which there are also differences in primary reinforcement frequencies. Preston and Fantino (1991) and Fantino et al. (in press) discussed a modification of the theory of Squires and Fantino (1971) wherein the frequencies of conditioned reinforcement were incorporated. They ar-gued that the modified model fared well only when sensitivity to this variable was assumed to be rather low.

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